Bulletin 1068 June 1997

Monitoring Node Above White Flower as Basis for Cotton Insecticide Treatment Termination

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Published June, 1997 by the Office of Agricultural Communications, Division of Agriculture, Forestry, and Veterinary Medicine, Mississippi State University. Edited by Keith H. Remy, Senior Publications Ediotr. Cover designed by Nikki Bane, Student Artist.

Preface

Data reported in this document are results of experiments conducted from 1993-1996. These experiments plus research reports and publications of University of Arkansas researchers show that the cotton insect control termination tactic under investigation has merit for Extension Service, agricultural consultant, and grower use. The Mississippi Cotton Insect Control Guide Committee includes the tactic in the annual Cotton Insect Control Guide. The content of this publication is a report of research results, including a brief review of other publications on the subject, a description of methods used in the studies, and data summaries in tables and graphs (figures). This publication is intended for researchers, extension specialists, and others interested in details of the research and its results.

A companion Mississippi Agricultural and Forestry Experiment Station bulletin, “Using NAWF Rules for Terminating Cotton Insect Control,” is being prepared by the authors for publication. It will contain a synopsis of research results, but the primary purpose will be to provide practical information to users of the tactic.

This report does not constitute a recommendation or warranty that the tactic will produce desired results in all situations in which it may be used. The authors, Mississippi State University, and the Mississippi Agricultural and Forestry Experiment Station assume no liability for yield loss or other damage that a user may perceive to have been the result of using the cotton insect control termination tactic discussed.

Acknowledgments

Experiments conducted in 1993, 1994, 1995, and 1996 in the Mississippi Delta were supported by Mississippi Agricultural and Forestry Experiment Station project number MIS-2130; and supported in part by Mississippi Cotton Incorporated State Support Program project number 95-161MS and Cotton Incorporated Core Program project number 95-245. Other Mississippi State University personnel serving in an advisory capacity to one or more of the above projects relative to research reported herein are M. B. Layton, R. G. Luttrell, W. H. McCarty, J. T. Reed, J. L. Willers, C. E. Watson, and M. R. Williams. Cotton Incorporated Core Program project number 95-245 is a multi-state coordinated research program with participants from Louisiana State University, Mississippi State University, Texas A & M University, University of Arkansas, and Virginia Polytechnic Institute and State University. All research reported herein was conducted in the Mississippi Delta by the authors, who gratefully acknowledge the advice, information, and encouragement provided by all other participants during the course of these studies.

We thank D. S. Calhoun, Agronomist, Delta Research and Extension Center, who assisted in these studies by contributing his effort and time in the attempt to infest plots with neonate tobacco budworm larvae in the small-plot replicated experiment conducted on Delta Branch Experiment Station in 1994.

We thank James T. Robbins, Assistant Entomologist, Delta Research and Extension Center, and Deborah L. Boykin, Statistician, USDA, ARS, who assisted in the analysis and presentation of data from the small-plot experiments.

We acknowledge and thank the important contribution to this research project of many cooperating cotton producers in the Mississippi Delta. These producers allowed testing of a new insect management tactic on part of their crop. They accepted an uncertain level of risk for the benefit of the project with hope that it would provide later benefits to themselves and all other cotton producers in the state.

Table of Contents

Monitoring Node Above White Flower as Basis for Cotton Insecticide Treatment Termination

Abstract

Small-plot replicated experiments and large-plot on-farm trials were conducted at several locations in the Mississippi Delta in 1993-1996 to test a cotton insect control termination rule. The objective was to test the hypothesis that monitoring node above white flower (NAWF) until crop development reaches the stage where the topmost white flower in the first position on a fruiting branch is five nodes below the terminal (NAWF=5) is a valid measure of "cutout," and that when 350 heat units (HU = DD60) have accumulated after NAWF=5, control of boll-feeding caterpillars (primarily bollworm and tobacco budworm) and reproductive boll weevils can be terminated. Cutout is the time when the last cohort of flowers that will produce harvestable bolls occurs in a crop. Results of the 1993-1996 studies indicate that NAWF=5 + 350 HU probably is a reliable indicator of when insect control can be terminated without adverse effect on yield and with a reduction in current levels of late-season insecticide use.

Introduction

Research using simulation models and empirical studies in field plots has indicated that current practices in application of insecticides probably extends into a period in late season when young bolls being protected have low probability of producing harvestable yield. Consequently, a precise and practical method of deciding when to terminate cotton insecticide applications has been tested for 4 years in the Mississippi Delta (1993, 1994, 1995, 1996). The technique allows determination of when the last cohort of harvestable bolls is mature, i.e. mature enough to have a low probability of insect damage. Its use may eliminate need for one to several late-season insecticide applications.

The crop status of "cutout" can provide a precise basis for termination of cotton insecticide treatment when cutout can be determined in a practical and reliable manner. A system has been developed for determining when a cotton plant reaches cutout – a system of counting nodes in the interval between uppermost white bloom on a plant and the mainstem terminal bud. The interval is called "**n**odes **a**bove **w**hite **f**lower" (NAWF). Research has shown that cutout is about NAWF=5, i.e. when the average NAWF count is 5 for a field of cotton, the cohort of bolls produced by those blooms will be the last the crop will develop into harvestable bolls. Research has shown that following anthesis (day of white bloom), a boll that accumulates 350 HU matures enough to have low probability of insect damage.

Cost of bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), in cotton in key cotton-producing areas of Arkansas, Louisiana, and Mississippi in 1992, more than doubled the average for the previous 5-year period (Head, 1993). Average costs per acre of control remained high in 1993, comparable to 1992 costs (Williams, 1994). Costs declined slightly in 1994, but remained relatively high (Williams, 1995). Cotton insect control costs in Mississippi in 1995 reflected an unusual event in the Hill area of the state, where growers spent more than $100 per acre for cotton insect pest control (higher cost than in the Delta for the first time ever recorded) and achieved poor control, including disastrous losses in some cases (Layton et al., 1996). Insecticide resistance in bollworm and tobacco budworm, especially pyrethroid insecticide resistance in tobacco budworm, is an important contributing factor in rising insect control costs (Elzen et al., 1993; Elzen et al., 1992; Graves et al., 1992; Luttrell et al., 1987). Use of the NAWF=5 + 350 HU rule for terminating cotton insect control may reduce number of insecticide applications, lower cost, and mitigate selection for insecticide resistance.

Review

Bollworm and tobacco budworm larvae show a preference for feeding on cotton flower buds ("squares") throughout their development, although later instar larvae will feed on cotton bolls (Townsend, 1973; Nicholson, 1975). Townsend (1973) infested plots with larvae during crop development periods that he defined as early-, mid-, and late-season. Early-season lint yield reduction was 5.6 g/larva, midseason lint yield reduction was 1.5 g/larvae, and late-season lint yield reduction was 1.0 g/larva. Nicholson (1975) found that both bollworm and tobacco budworm larvae had similar feeding behavior on squares and bolls, and that relatively few fruit of ages representing bolls were attacked during larval developmental periods compared to number of squares attacked. Curvilinear regression equations were developed from these data and utilized in a bollworm/tobacco budworm feeding model.

Nicholson's equations were utilized in a cotton insect management (CIM) simulation model developed to study cotton insect management strategies (Brown et al. 1982). The CIM model simulated cotton crop growth and development and bollworm, tobacco budworm and boll weevil, *Anthonomus grandis* Boheman, population development interacting with the host crop. Brown and McClendon (1982) used the CIM model to simulate various scenarios of weather data (10 years) and six different insect pest population combinations. With these simulation studies, they developed a hypothetical dynamic treatment threshold, which was lower during fruit set and higher as fruit matured. The simulations predicted that use of such a dynamic threshold would protect the harvestable cotton crop with fewer insecticide applications, earlier termination of insect control, lower cost of control, and higher yield.

Luttrell et al. (1983) used CIM model simulations to study cotton insect treatment thresholds and concluded that a mechanism was needed "in current recommendations to determine when insect control may cease during the late portion of the growing season." Kitten and Luttrell (1983) conducted field studies at five locations in Mississippi to compare the dynamic treatment threshold strategy proposed by Brown and McClendon (1982) to Mississippi's current insect control strategy. Current insect control strategy in 1983 (Mississippi Cooperative Extension Service) recommendations used an essentially constant treatment threshold during the growing season.

Kitten and Luttrell (1983) found that the dynamic treatment threshold strategy required the same number of insecticide applications as current insect control recommendations, but the dynamic threshold strategy resulted in more early and midseason applications. The dynamic threshold strategy probably erred in triggering too frequent early and/or midseason insecticide applications and could have been modified to correct that deficiency. Kitten and Luttrell (1983) concluded that current insect control recommendations resulted in unnecessary late-season applications after peak boll set that protected fruit which would not contribute to yield. They suggested additional work to correct that deficiency in Mississippi's insect control recommendations.

Additional field trials have been conducted using the CIM model for computer-assisted management and comparing the dynamic threshold strategy to current insect control strategy (Andrews et al., 1984). However, little progress has been made in adapting the system to reduce unnecessary late-season insecticide applications.

A different approach to the problem of terminating late-season insecticide applications has been taken in recent years. Numerous researchers have reported the phenomenon of rapid mainstem terminal meristem growth in cotton prior to bloom followed by a slowing of terminal growth as a normal cotton plant blooms and sets bolls (Eaton, 1955; Ehlig and Lemert, 1973; Patterson et al., 1978; Verhalen et al., 1975). Stringer et al. (1989) showed how this process reaches a relatively discreet point, which may be used as a signal that the plant has reached "cutout." Cutout is defined by Oosterhuis et al. (1993) as "an empirical term often used to signify the cessation or extended lapse in terminal growth due to the development of the boll load sink and the resulting demand for available nutrient and photosynthate resources." It is the crop status of "cutout," which, when determined in a practical and reliable manner, provides a precise basis for termination of cotton insecticide treatments.

Bernhardt et al. (1986) published a definitive and seminal paper on use of uppermost white flower position relative to the mainstem terminal bud (determined by node counts) as an indicator of when to terminate insecticide treatments in cotton. They proposed use of the interval, expressed in number of nodes, between a white flower and the mainstem terminal meristem as a measure of crop status relative to cutout. A white flower is a cotton flower with white petals that occurs on the day of anthesis (Oosterhuis et al., 1993). The flower petals turn pink then red on subsequent days. Bernhardt et al. (1986) proposed that the uppermost white flower counted should be at the first position of a sympodial branch and that the terminal count should be defined as at the node of the first unexpanded mainstem leaf. Therefore, to determine the interval between uppermost white flower (first position on sympodial branches) and the terminal, the node above the white flower was counted as the first and the node of the first unexpanded mainstem leaf was counted as the last. This later was given the acronym NAWF (Oosterhuis et al., 1993).

Bernhardt et al. (1986) tested the hypothesis that cutout of cotton plants can be determined by counting NAWF, and that the bolls produced by flowers blooming at cutout are the last harvestable bolls the crop will produce. They determined that cutout was when terminal growth slowed and first position white flowers occurred within four nodes of the terminal, i.e., NAWF=4. They showed in field experiments that production of lint produced by bolls from blooms occurring after NAWF=4 was less than 1% of total yield. They proposed that a cotton crop should be protected against bollworm and tobacco budworm damage for 10 days after crop status is determined to be NAWF=4, and protected against boll weevil damage for 16 days after NAWF=4.

Recent research has resulted in the determination that cutout is defined as NAWF=5 for Arkansas growing conditions (Bourland et al., 1992; Oosterhuis et al., 1993). Other recent research has provided information to make the NAWF crop status concept applicable to a broad range of growing conditions. Growth curves of cotton crops may be categorized into two general growth patterns based on monitoring NAWF, type I or type II (Oosterhuis et al., 1993). Type I growth and development progresses without undue stress and at first flower NAWF is 8 to 10 followed by a steady decline to NAWF=5 (cutout) at an early target date, i.e. 80-85 days after planting. Type II growth and development occurs where some plant stress has been experienced and NAWF at first flower is less than 8, followed by various irregular patterns of NAWF progression (variations of plateau and decline) until NAWF=5 (cutout) is reached at a late date.

Klein et al. (1994) showed variations in actual type I and type II growth patterns compared to a hypothetical ideal type I. Bagwell and Tugwell (1992) and Bagwell (1994) showed that bolls accumulating 350 heat units (HU) after flowering have matured sufficiently to have a low probability of attack by boll weevil and bollworm. Therefore, a hypothetical precise method for deciding when to terminate would be to monitor NAWF to NAWF=5 then accumulate 350 HU (i.e. NAWF=5 + 350 HU) and cease application of insecticides. A heat unit (HU) is based on 60 °F and is defined as (daily max. °F + daily min. °F)÷2 – 60°F. Harris et al. (1995), reporting on research in the Mississippi Delta, suggested that NAWF=5 + 350 HU may be a conservative indicator of when cotton insect control can be stopped with little risk of reducing profit.

COTMAN is a computer-aided expert system for late-season COTton MANagement (Zhang et al., 1993). Input for COTMAN is plant monitoring data, long-term and current weather data, and farm and field information. The user's guide states that "COTMAN is divided into two major components: SQUARMAN and BOLLMAN. SQUARMAN is the early-season component and defines quantitative measures of fruiting node development, fruit retention and elongation rates. BOLLMAN functions as a decision-aid to the diagnosis of plant growth status, timing of insecticide termination, and timing of defoliation and harvest scheduling" (Anonymous, 1995).

Cochran et al. (1994) analyzed results of a grower survey for economic benefits of using NAWF=5 + 350 HU decision rule for terminating cotton insect control. They showed that in southeast Arkansas, where cotton insect infestation pressure was greatest in the state, use of the decision rule resulted in potential reductions of 2.65 insecticide applications per acre and insect control cost savings of almost $26 per acre, compared to local farmer practices. They also estimated that under ideal management situations average reduction of almost four insecticide applications may be achieved in some production areas of Arkansas.

Rationale and Significance

An insect management system closely tied to crop development and based on a goal of optimum fruit initiation, development, and maturity will provide the basis for reducing total number of insecticide applications made to cotton during a growing season. Fewer insecticide applications probably will result in a much needed lower cotton insect control cost and a desirable reduction in insecticide load in the environment. Fewer insecticide applications will also reduce selection for insecticide resistance. Elimination of unnecessary late-season insecticide applications to cotton may be especially important in managing insecticide resistance in tobacco budworm, a pest that typically invades Midsouth cotton at highest population densities in August and September.

Current cotton insect management decisions are based on "thresholds" called economic thresholds, action thresholds, or treatment thresholds. In practice, the threshold that an insect management decision-maker must use is a loosely structured and somewhat intuitively developed system of monitoring insect pest infestation or injury level, predicting changes in these infestation or injury levels for some scouting time interval, predicting effect on final crop yield, and to some degree calculating an estimate of cost and return for a control treatment. The process is a complicated one done with guidance from a set of recommendations, which are usually partitioned into discrete units for single insect pests, and which are limited in relating control advice to cotton crop development. Guidance is also limited or essentially nonexistent for crop management decision-makers on how to determine when cotton fruit is mature sufficiently to have a low risk of further insect damage.

Research has provided an information base, monitoring system, and computer-aided expert system by which cotton insect management decisions may be guided. This work provides a foundation upon which decisions for terminating end-of-season cotton insect control may be based, and which may be applicable across the Midsouth cotton production region.

The key criterion proposed to be used in end-of-season insect management decisions is number of mainstem nodes above the uppermost white flower (NAWF). NAWF is an important decision criterion because it is indicative of crop status from first flower through cutout, and it can be easily and quickly monitored. NAWF is a measure of growth rate of the mainstem terminal meristem relative to vertical flowering rate of first position sympodial flower buds (squares). Flowering rate, i.e. time interval between blooms, is relatively consistent and determined primarily by temperature. Growth rate of mainstem terminal meristem is highly variable and influenced by stresses, which may be related to weather, soil type, soil fertility, soil moisture; or it may be influenced by boll load (number of cotton fruit relative to plant capacity to retain and develop fruit). Therefore, monitoring NAWF provides a practical and dynamic measure of crop development by which goals of crop progress can be gauged and upon which management decisions can be based.

Changing to Weather-based Rules for Insect Control Termination in Type II Crops

The rules for terminating cotton insect control based on NAWF work best on type I cotton crops (nonstressed, optimum growth). Some type II cotton crops will be delayed sufficiently to force a change to a weather-based rule for deciding when to terminate insect control. When a weather-based rule for insect control termination is used, choices must be made about (1) acceptable probability of maturing a bloom into a harvestable boll, and (2) latest acceptable defoliation date. For example, a grower may accept an 85% probability of sufficient heat units (750 HU minimum) to mature the latest population of blooms into bolls that can be defoliated on October 1. In that case, August 11 is the latest date of effective blooms at the Stoneville, MS latitude, and the crop would be protected from insect damage through accumulation of 350 HU after August 11 (Figure 1). The graph in Figure 1 shows percent probability of accumulating 750 HU for blooms on various dates by four target defoliation dates and by the average freeze date. These probabilities were from 29 years of weather data at Stoneville, MS. Such probabilities can be developed for other latitudes in Mississippi and for different HU accumulations (such as a more conservative 850 HU needed to mature bolls), and used by growers to help with decisions about late season investment in insect control on late crops.

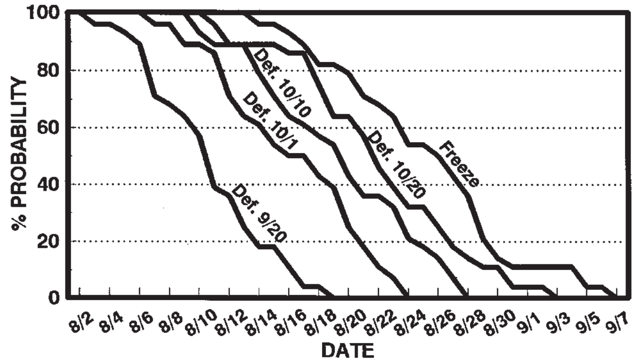

Figure 1. Probability of blooms accumulating 750 HU by indicated defoliation date, where 750 HU equals minimum time needed for boll maturity from bloom to defoliation, and where percent probability for HU accumulation is based on 29 years of weather data at Stoneville, MS.

COTTON INSECT CONTROL TERMINATION EXPERIMENTS, 1993-1996

Methods and Materials

Field Trial, Small Plot, 1993

Three varieties (DES 119, Hartz 1244, and DPL 5415) were planted in a split-plot experiment replicated six times on Delta Branch Experiment Station, Stoneville, MS. Treatments within each variety were 4 HU accumulations from NAWF=5 to insect control termination. Arrangements of treatments in the field design were in split-plots within randomized complete blocks. However, HU accumulation treatments were not consistent for all varieties because of an error in the formula used in measuring HU accumulation for two of the varieties. Therefore, treatments within each variety were treated as a separate experiment. HU accumulation treatments and date of occurrence within varieties were as follows:

DES 119 - (1) NAWF=5 + 0 HU (Aug 7)
(2) NAWF=5 + 217 HU (Aug 16)
(3) NAWF=5 + 296 HU (Aug 19)
(4) NAWF=5 + 426 HU (Aug 24)

H 1244 - (1) NAWF=5 + 0 HU (Aug 7)
(2) NAWF=5 + 217 HU (Aug 16)
(3) NAWF=5 + 296 HU (Aug 19)
(4) NAWF=5 + 426 HU (Aug 24)

DPL 5415- (1) NAWF=5 + 0 HU (Aug 16)
(2) NAWF=5 + 282 HU (Aug 26)
(3) NAWF=5 + 453 HU (Sep 2)
(4) NAWF=5 + 608 HU (Sep 12)

Plots were planted May 19, 1993, in a 4 x 4 skip-row pattern so that each plot was 4 rows wide by 50 feet long and bordered on each side by a 4-row fallow strip.

No insect control treatment applications were made to plots of a treatment after the indicated NAWF=5 + HU accumulation occurred. Prior to NAWF=5 (Aug 7 for two varieties) the entire test was treated with insecticides as follows: Orthene 90S (0.75 lb ai/A) in-furrow spray at planting May 19 for thrips control, Guthion (0.25 lb ai/A) June 29 and July 9 for boll weevil control, and Scout + Larvin (0.024 + 0.25 lb ai/A) July 27 and August 5 for bollworm/tobacco budworm control.

Insecticide applications made to DES 119 and Hartz 1244 plots were initiated when average larval-damaged squares was greater than 4%, but a minimum of one treatment was applied in the interval between termination dates for those treatments continuing to receive insect control applications. Similar criteria applied to DPL 5415 plots, but more frequent applications were required because of the developing beet armyworm infestation in late August and into September. The maintenance insecticide treatment schedule, the late-season treatment schedule, and heat units accumulated are presented in Table 1.

Counts of bollworm/tobacco budworm infestation (eggs and larvae), and counts of squares damaged by bollworm/tobacco budworm larvae or by boll weevil were made July 22 and 26, and August 9, 16, 23, and 30. Bollworm/tobacco budworm infestation was light to mod-

Table 1. Insecticide treatment schedule, bollworm/tobacco budworm late season treatment termination experiment. Stoneville, MS. 1993.

			Cotton Variety and Treatment Number[1]											
	Comments		DES 119				H 1244				DPL 5415			
Date	**Insecticide**	**Rate, lb ai/A**	**1**	**2**	**3**	**4**	**9**	**10**	**11**	**12**	**5**	**6**	**7**	**8**
5/19	Orthene 90S	(.75) IFS2	X	X	X	X	X	X	X	X	X	X	X	X
6/29	Guthion	(.25) X	X	X	X	X	X	X	X	X	X	X	X	X
7/9	Guthion	(.25) X	X	X	X	X	X	X	X	X	X	X	X	X
7/27	Scout + Larvin	(.024 + .25)	X	X	X	X	X	X	X	X	X	X	X	X
8/5	Scout + Larvin	(.024 + .25)	X	X	X	X	X	X	X	X	X	X	X	X
8/7	DES 119 (TR 1-4) and H 1244 (TR 9-12) reached NAWF-5													
8/11	Scout + Curacron	(.024 + .25)		X	X	X		X	X	X	X	X	X	X
8/16	217 HU accumulated since 8/7													
8/16	DPL 5415 (TR 5-8) reached NAWF-5 treated on 8/17 before confirmation													
8/17	Scout + Curacron	(.024 + .25)			X	X			X	X	X	X	X	X
8/19	296 HU accumulated since 8/7													
8/19	Scout + Orthene	(.024 + .25)				X				X		X	X	X
8/24	426 HU accumulated since 8/7, 233 HU accumulated since 8/16													
8/24	Karate + Orthene	(.025 + .5)										X	X	X
8/26	282 HU accumulated since 8/16													
8/26	Karate + Larvin	(.025 + .25)											X	X
8/31	Karate + Larvin	(.025 + .25)											X	X
9/2	453 HU accumulated since 8/16													
9/2	Karate + Larvin	(.025 + .25)												X
9/7	Karate + Larvin	(.025 + .25)												X
9/12	608 HU accumulated since 8/16													
9/24	Def + Prep	(1 pt. + 1 qt.) All plots defoliated												

[1]Insecticide application indicated by “X” in a treatment column for the date.
[2]IFS = In-furrow spray at planting.

erate, with egg density highest on August 16, and average per 100 terminals for the three varieties ranged from 11 to 34 on that date. Average larval damaged squares during this peak infestation period ranged from approximately 2% to 9%. Boll weevil infestation was very light. A beet armyworm infestation started in late August and by late September had caused heavy leaf damage in the plots.

Plots were harvested October 11 with an International Harvester model 622 cotton picker. All rows (4) per plot were picked for yield estimates, 200 row feet per sample, and data were converted to pounds of seed cotton per acre. Samples were not ginned to determine percent turnout. Lint yield estimates were based on 35% lint turnout.

Field Trial, Small Plot, 1994

DES 119 cotton variety was planted in a small plot replicated experiment on Delta Branch Experiment Station, Stoneville, MS in 1994. Treatments were 5 HU accumulations from NAWF=5 to insect control termination. HU accumulation treatments with date of occurrence (i.e. date of treatment termination) were as follows:

(1) NAWF=5 + 0 HU (Jul 29)
(2) NAWF=5 + 189 HU (Aug 8)
(3) NAWF=5 + 392 HU (Aug 18)
(4) NAWF=5 + 600 HU (Aug 29)
(5) NAWF=5 + 790 HU (Sep 9)

Plots were planted on April 27 in a 4 x 4 skip-row pattern. Treatments were arranged in randomized complete blocks replicated six times.

No insect control treatment applications were made to plots of a treatment after the indicated NAWF=5 + HU accumulation occurred. Prior to NAWF=5 (July 29) the entire test was treated with insecticides as follows: At planting seed treatment or in-furrow granule (product and rate not recorded); Orthene 90S + methyl parathion 4E (0.25 + 0.25 lb ai/A) applied May 27, June 3, and June 10 for tarnished plant bug and boll weevil control; Bidrin 8L (0.5 lb ai/A) applied July 6 for cotton aphid control; and Scout X-TRA + Orthene (0.024 + 0.75 lb ai/A) applied July 20 for bollworm/tobacco budworm control.

Bollworm/tobacco budworm infestation was low during the late-season termination treatment period. Infestation with neonate tobacco budworm larvae from a laboratory culture was attempted. Tobacco budworm eggs were obtained from the USDA, ARS, Southern Insect Management Laboratory, Stoneville, MS. Eggs were mixed with hydrated corn grits and allowed to hatch. Hatched neonate larvae in hydrated corn grits were applied to 50 terminals per 50 row feet on each of the four rows per plot. Applicators placed 0.3 ml of mixture (corn grits and larvae) per application or “shot.” Applications of larvae were made on two dates, August 4 and 11. Larvae per “shot” averaged 8.4 August 4, with a 14.3% estimate of mortality during handling on the day of application. Larvae per "shot" averaged 13.8 August 11, with a 15% estimate of mortality during handling on the day of application. Observations of larval infestation and damage in plots following the second artificial infestation with neonate larvae did not indicate successful establishment of tobacco budworm larvae in the plots. Treatment thresholds were not reached in any plot.

Late-season insecticide applications were made to a treatment on the date that HU accumulation reached the appropriate level for termination for that treatment. Other treatments that had not yet reached the HU accumulation indicated for termination were also treated on these dates. NAWF=5 was reached July 29 in the plots and the following spray schedule after NAWF=5 shows the treatments that continued to receive insecticide application after each treatment termination date: (1) NAWF=5 + 0 HU (Jul 29); treatments 1, 2, 3, 4, 5 sprayed, (2) NAWF=5 + 200 HU, actual HU=189 (8 Aug); treatments 2, 3, 4, 5 sprayed, (3) NAWF=5 + 400 HU, actual HU=392 (Aug 18); treatments 3, 4, 5 sprayed, (4) NAWF=5 + 600 HU, actual HU=600 (Aug 25 and 29); treatments 4, 5 sprayed, (5) NAWF=5 + 800 HU, actual HU=790 (Sep 9) treatment 5 sprayed and all plots defoliated. Insecticide applications to the treatments after NAWF=5 were Scout X-TRA + Orthene (0.024 + 0.9 lb ai/A) July 29, and August 8 and 18; Scout X-TRA + Orthene + Confirm (0.024 + 0.9 + 0.125 lb ai/A) August 25; and Karate + Orthene (0.03 + 0.9 lb ai/A) August 29.

NAWF counts were made on 20 plants per plot (5 plants/row) July 6, 20, 25, and 29, and August 1, 5, 8, and 12. Node above cracked boll (NACB) counts were made on 20 plants per plot (5 plants/row) September 1 and 7.

Plots were harvested October 4 with an International Harvester model 622 cotton picker. All rows (4) per plot were picked for yield estimates and weighed as 200 row feet seed cotton samples. Yield data were converted to pounds of seed cotton per acre. Samples were not ginned to determine percent turnout. Lint yield estimates were based on 35% lint turnout.

Field Trial, Small Plot, 1995

An experiment was initiated on a farm in Leflore County where a boll weevil and bollworm/tobacco budworm infestation potential existed. Treatments were different HU accumulations after NAWF=5 as follows: Terminate insect control for each treatment at

(1) NAWF=5 + 137 HU (Aug 8)
(2) NAWF=5 + 277 HU (Aug 14)
(3) NAWF=5 + 386 HU (Aug 18)
(4) NAWF=5 + 488 HU (Aug 22)
(5) NAWF=5 + 631 HU (Aug 28)

When a treatment was terminated an insecticide treatment was applied to that treatment and all other treatments that had not been previously terminated.

Treatments were arranged in a randomized complete block replicated three times. Planting pattern in the field was 2 x 1 skip-row. Planting date was May 15. Cotton variety was Stoneville 474. Plot size averaged 3 acres (2 acres of planted cotton rows).

The crop reached NAWF=5 August 3. Insecticides applied the date of each treatment termination were as follows:

(1) NAWF=5 + 137 HU (Aug 8)
Karate + Confirm (0.033 + 0.125 lb ai/A) applied to treatments 1 - 5,
(2) NAWF=5 + 277 HU (Aug 14)
Larvin + Ovasyn + Methyl parathion (0.53 + 0.1875 + 0.33 lb ai/A) applied to treatments 2 - 5,
(3) NAWF=5 + 386 HU (Aug 18)
Karate + Confirm (0.04 + 0.125 lb ai/A) applied to treatments 3 - 5 (Confirm 0.125 lb ai/A applied to treatments 1 & 2 Aug 19 for beet armyworm control),
(4) NAWF=5 + 488 HU (Aug 22)
Larvin + Lannate + Methyl parathion (0.4 + 0.24 + 0.33 lb ai/A) applied to treatments 4 - 5,
(5) NAWF=5 + 631 HU (Aug 28)
Larvin + Lannate + Methyl parathion (0.4 + 0.2 + 0.25 lb ai/A) applied to treatment 5.

Field Trial, Small Plot, 1996

The test was conducted at one site in Carroll County near Greenwood, MS. Cotton variety was Sure Grow 125. Plot size was approximately 3 acres. The following four treatments were replicated three times in randomized complete blocks and are expressed as the heat unit accumulation after NAWF=5 when the last insecticide application was made to the treatment:

(1) NAWF=5 + 98 HU (Jul 20)
(2) NAWF=5 + 287 HU (Jul 29)
(3) NAWF=5 + 381 HU (Aug 3)
(4) NAWF=5 + 712 HU (Aug 20)

Treatments were determined by the grower cooperator's spray schedule based on his determination of need (private consultant's spray recommendation).

The crop reached NAWF=5 July 17. Dates of termination for each treatment and the insecticides applied were as follows:

(1) NAWF=5 + 98 HU (Jul 20)
Karate (0.035 lb ai/A) applied to treatments 1-4,
(2) NAWF=5 + 287 HU (Jul 29)
Karate (0.037 lb ai/A) applied to treatments 2-4,
(3) NAWF=5 + 381 HU (Aug 3)
Decis (0.018 lb ai/A) applied to treatments 3-4,
(4) NAWF=5 + 712 HU (Aug 20)
Karate (0.033 lb ai/A) applied to treatment 4.

Field Trials, Large Plot, 1994

Large-plot field trials were established with producers at four sites (each treated as a replicate) in the Mississippi Delta in 1994. Field design was a 2x2 split plot. Whole-plot treatments were (1) EP = early-season treatment with pyrethroid insecticides, and (2) CIC = early-season treatment with organophosphate insecticides based on current-insect-control recommendations. Early season was the period of 14 days beginning with the fourth true-leaf stage of crop development. Whole-plot treatments were applied to adjacent whole fields ranging in size from 20 to 40 acres. Each field was divided into two subplots to which split-plot treatments were applied (1) ET = early termination, in which late-season insect control was terminated **at or before** NAWF=5 + 350 HU; and (2) FS = full season, in which insecticide treatment **continued after** NAWF=5 + 350 HU according to the grower/consultant decision.

No insecticide was applied to the early termination treatment after NAWF=5 + 350 HU and the last application prior to NAWF = 5 + 350 HU was based on a treatment threshold of four bollworm/tobacco budworm larvae per 100 terminals and/or 10% boll weevil damaged squares.

Site 1 was in Leflore County, MS. Plots were planted April 23 to DES 119 cotton variety. Subplot 1 reached NAWF=5 July 18 and subplot 2 reached NAWF=5 July 25.

Site 2 was in Yazoo County, MS. Plots were planted April 25 to Deltapine 20 cotton variety. Subplot 1 reached NAWF=5 August 10 and subplot 2 reached NAWF=5 August 8.

Site 3 was in Sunflower County, MS. Plots were planted April 27 to Deltapine 20 cotton variety. Both subplot 1 and subplot 2 reached NAWF=5 August 14.

Site 4 was in Bolivar County, MS. Plots were planted May 21 to Suregrow 501 cotton variety. Subplot 1 reached NAWF=5 August 8 and subplot 2 reached NAWF=5 August 7.

Insect infestation and damage observations were made throughout the growing season. Site 1 was an area heavily infested with boll weevil. Site 2 had a heavy tarnished plant bug infestation and was a late-developing crop. Site 3 was damaged by a hailstorm in June and the crop reached NAWF=5 later than at other sites, but maturity then proceeded rapidly due to drought stress in August. Sites 3 and 4 had only light boll weevil and almost no tarnished plant bug infestations. All sites had a persistent light to moderate bollworm/tobacco budworm infestation through July and into August.

NAWF counts were made from mid-July through August. **N**ode **a**bove **c**racked **b**oll (NACB) data were recorded from mid-August until NACB=4, which was considered the appropriate time to defoliate the plots (Kirby et al. 1992, Supak et al. 1993).

When the crop reached NAWF=5, 50 to 100 white blooms per plot were tagged for later observation of percent set and lint yield. These bolls, and any bolls at higher position nodes, were collected after defoliation and before harvest and held in a laboratory at room temperature until dry. Seed cotton was harvested from the bolls and pooled for each position, i.e. (1) NAWF=5 position, (2) one node above NAWF=5 position, and (3) two nodes above NAWF=5 position. The pooled ginned lint sample was weighed and an average lint weight per boll was determined for each position. Percent boll set was also calculated for each of the three positions sampled by this method.

Each subplot was harvested with the cooperator's mechanical harvester, eight rows the full length of the subplots, and seed cotton was weighed in a boll buggy equipped with scales.

Field Trials, Large Plot, 1995

Large-plot on-farm experiments were established at 13 locations in the Mississippi Delta. The following two treatments were replicated one to three times at each location: (1) ET = early termination **at or before** NAWF=5 + 350 HU, and (2) FS = full season in which insecticide treatment **continued after** NAWF=5 + 350 HU (grower standard).

Plots ranging in size from 4 to 10 acres were flagged on the day of NAWF=5 + 350 HU to indicate termination of insect control in treatment 1 and continuing insect control in treatment 2. Data from treatment 2 were analyzed if the grower applied one or more insecticide applications after treatment 1 insect control was terminated at NAWF=5 + 350 HU and there was a measurable insect infestation (bollworm/tobacco budworm and/or boll weevil) during an observation period after NAWF=5. Growers at two locations terminated all cotton insect control at or before NAWF=5 + 350 HU so plots on those two farms were not harvested. Plots on another two farms were harvested but seed cotton weights showed very large differences in treatments — several hundred pounds per acre higher in treatment 1 on one farm, and several hundred pounds per acre higher in treatment 2 on the other farm — with no other substantiating evidence that such differences were real. Sample weight errors were suspected. Therefore, data from these two farms were not used in analyses. Two other farms showed little or no insect pest infestation during the late-season period and yield data were not used in analyses. Consequently, data from 6 of the 13 farms were not used in analyses and data from 7 of the 13 farms were used in analyses.

Field Trials, Large Plot, 1996

Fields were monitored for crop development on seven farms during the 1996 growing season. Six of these farms were used for termination experiments. The seventh farm received no additional insecticide applications after NAWF=5 + 350 HU. An additional two farms with late-planted or replanted crops were monitored to test weather-based rules for termination of insect control on cotton crops that mature late.

The following two treatments were replicated three times (except for one site where treatments were unreplicated) in one of the fields monitored per farm: (1) ET = early termination **at or before** NAWF=5 + 350 HU; and (2) FS = full season, in which insecticide treatment **continued after** NAWF=5 + 350 HU (grower standard).

Plot size was approximately 10 acres so that the two treatments replicated three times involved approximately 60 acres per site.

Additional insecticide treatments applied to the full-season plots were determined by insect infestation counts and a judgement to treat by the grower and/or agricultural consultant.

Plots were harvested with the grower cooperator's cotton picker and weighed with a boll buggy modified for weighing samples.

Data

COTMAN, a computer-aided expert system developed at the University of Arkansas, was used to project the last effective boll population (i.e. NAWF=5) in plots, and was used for calculating heat units (HU). COTMAN was also used to calculate the date to terminate insecticide applications in large plot early termination treatments (i.e. date of NAWF=5 + 350 HU).

The following data were recorded for each plot in both the small-plot replicated experiments and the large-plot on-farm trials in 1995 and 1996. Some, but not all, of these observations and data records were made in the 1993 and 1994 studies. Selected data are summarized in this document.

Insect infestation and damage

Tarnished plant bug adults and nymphs (sweep net counts).

Bollworm/tobacco budworm eggs in terminals (25 or 50 per observation).

Bollworm/tobacco budworm larvae in terminals (25 or 50 per observation).

Bollworm/tobacco budworm larval damaged squares (% based on 25 or 50 squares per observation).

Bollworm/tobacco budworm larval damaged bolls after NAWF=5 (% based on 25 or 50 bolls per observation).

Boll weevil damaged squares (% based on 25 or 50 squares per observation).

Plant monitoring and yield data

Daily maximum and minimum temperatures from first bloom to defoliation.

Plant monitoring with inputs for COTMAN (both SQUARMAN and BOLLMAN data requirements), including plant mapping first position fruit set from first square to bloom, node above white flower (NAWF) from first bloom to NAWF=5.

Node above cracked boll (NACB) from NAWF=5 to NACB=4 in some tests.

Yield: Seed cotton yield was harvested and bagged with plot pickers (modified commercial cotton pickers) in small plots and weighed. Large plots were harvested with farmer cooperator machines and weighed with a boll buggy modified for research plot work. Subsamples were taken for lint turnout, quality determinations, and other measurements as needed.

Economic data (inputs and costs)

All practices and costs.

Insecticide application dates, rates, and costs (both treatments and whole farm).

Results

Field Trial, Small Plot, 1993

Bollworm/tobacco budworm and boll weevil infestation data are summarized in Tables 2-5 for the three varieties in 1993 experiments. These data show relatively light to moderate infestation potential from late July through August. Means of infestation levels and damage shown in Tables 2-5 suggest damage potential from the bollworm/tobacco budworm infestation. The data for termination treatment within variety showed few significant differences (LSD p=.05) in larval infestation or damage level. Boll weevil damaged squares showed slightly higher percent damage level on later observation dates (not statistically significant, LSD p=.05) in the early termination treatments (Table 5).

Mean lint yield per acre data, calculated as 35% of seed cotton yield estimates, are summarized for DES 119, Hartz 1244, and Deltapine 5415 in Figures 2, 3, and 4. Yield results for treatments in DES 119 variety summarized in Figure 2 show an increase in average yield for each later insect control termination treatment but with a smaller increment of increase with each later treatment. An unfortunate error in calculating heat units for the two varieties that reached NAWF=5 on August 7 resulted in shorter intervals than desired between termination treatments. Nevertheless, the yield response tends to support the hypothesis that cotton yield response to late season insecticide applications will plateau at NAWF=5 + 350 HU.

Mean lint yield per acre estimates for Hartz 1244 in Figure 3 show some similarity in response to the insect con-

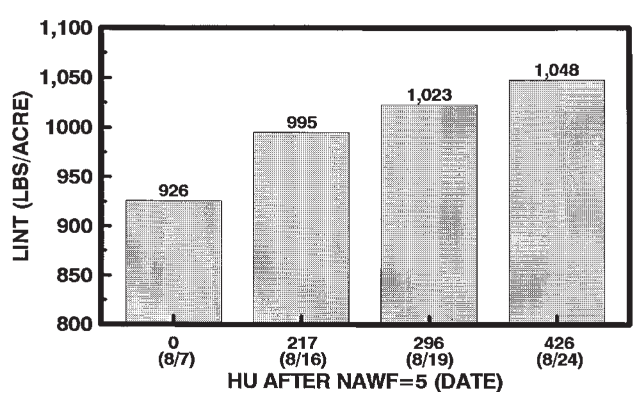

Figure 2. Average lint per acre yield for cotton insecticide termination treatments, DES 119 cotton variety, 1993 experiment at Stoneville, MS. Harvested Oct. 11. LSD (p=.05) = 42 and CV = 3.4.

Table 2. Mean bollworm/tobacco budworm eggs per 100 terminals for each variety and HU accumulation treatment on seven observation dates in 1993 cotton insect control termination small plot experiment. Stoneville, MS.

HU Accumulation after NAWF=5 (date)	7/22	7/26	8/2	8/9	8/16	8/23	8/30
DES 119							
0 (Aug 7)	0.7	0.7	8.0	3.3	10.7	0.7	6.7
217 (Aug 16)	0.7	0.7	5.3	10.0	18.0	3.3	6.0
296 (Aug 19)	1.3	2.0	6.7	7.3	13.3	4.7	5.3
426 (Aug 24)	0.7	0.7	8.0	7.3	18.7	6.0	4.0
LSD (p=.05)	1.9	1.8	6.0	10.3	11.0	5.3	6.8
Hartz 1244							
0 (Aug 7)	0.0	1.3	2.7	6.7	17.3	4.0	7.3
217 (Aug 16)	0.7	0.7	4.0	7.3	24.0	3.3	8.0
296 (Aug 19)	0.7	2.7	8.0	6.7	19.3	5.3	8.7
426 (Aug 24)	0.0	0.7	4.0	7.3	34.0	12.0	10.0
LSD (p=.05)	1.5	3.6	6.4	7.5	14.1	6.3	7.4
DPL 5415							
0 (Aug 16)	0.7	0.0	5.3	13.3	19.3	9.3	14.0
282 (Aug 26)	0.0	1.3	8.0	12.0	23.3	4.0	8.0
453 (Sep 2)	3.3	1.3	5.3	11.3	26.0	8.0	9.3
604 (Sep 12)	1.3	5.3	6.0	9.3	24.7	5.3	16.0
LSD (p=.05)	3.7	3.0	5.2	10.1	14.5	5.4	12.8

Each mean an average of data from six replications.

Table 3. Mean bollworm/tobacco budworm larvae per 100 terminals for each variety and HU accumulation treatment on seven observation dates in 1993 cotton insect control termination small-plot experiment. Stoneville, MS.

HU Accumulation after NAWF=5 (date)	7/22	7/26	8/2	8/9	8/16	8/23	8/30
DES 119							
0 (Aug 7)	0.0	0.0	0.0	0.0	1.3	0.0	0.0
217 (Aug 16)	0.0	1.3	0.0	1.3	1.3	0.7	0.0
296 (Aug 19)	1.3	2.0	2.0	1.3	0.7	0.7	0.7
426 (Aug 24)	0.7	1.3	1.3	2.0	0.7	0.0	0.7
LSD (p=.05)	1.9	2.4	2.1	2.8	1.9	1.5	1.5
Hartz 1244							
0 (Aug 7)	0.0	0.0	1.3	2.0	0.0	1.3	0.0
217 (Aug 16)	0.0	1.3	1.3	0.7	0.7	0.0	0.0
296 (Aug 19)	0.0	0.7	2.7	1.3	0.0	0.7	0.7
426 (Aug 24)	0.7	0.0	2.0	1.3	2.0	0.0	0.0
LSD (p=.05)	1.0	2.3	1.9	2.7	1.6	2.0	1.0
DPL 5415							
0 (Aug 16)	0.0	0.0	1.3	2.0	0.7	1.3	1.3
282 (Aug 26)	0.0	0.0	0.7	0.7	0.7	0.0	0.0
453 (Sep 2)	0.0	1.3	1.3	2.0	1.3	0.0	1.3
604 (Sep 12)	0.0	0.7	0.0	2.0	0.0	0.0	0.7
LSD (p=.05)	0.0	2.3	2.5	2.7	1.9	2.3	2.5

Each mean an average of data from six replications.

Table 4. Mean bollworm/tobacco budworm percent larval damaged squares for each variety and HU accumulation treatment on seven observation dates in 1993 cotton insect control termination small-plot experiment. Stoneville, MS.

HU Accumulation after NAWF=5 (date)	7/22	7/26	8/2	8/9	8/16	8/23	8/30
DES 119							
0 (Aug 7)	0.0	0.7	1.3	2.0	4.7	1.3	4.0
217 (Aug 16)	0.0	2.0	0.7	6.0	5.3	1.3	4.0
296 (Aug 19)	2.7	2.7	3.3	3.3	4.7	4.7	2.7
426 (Aug 24)	0.7	1.3	1.3	4.7	1.3	1.3	6.7
LSD (p=.05)	2.8	3.3	4.0	3.3	2.8	4.0	5.7
Hartz 1244							
0 (Aug 7)	0.0	2.0	4.7	6.7	2.7	0.0	6.0
217 (Aug 16)	0.0	2.0	4.0	6.7	3.3	0.0	5.3
296 (Aug 19)	0.0	1.3	4.0	8.7	4.7	0.7	4.7
426 (Aug 24)	0.7	0.0	4.0	6.0	3.3	0.7	4.7
LSD (p=.05)	1.0	3.7	5.5	3.8	2.7	1.5	5.6
DPL 5415							
0 (Aug 16)	0.0	1.3	3.3	6.0	1.3	1.3	2.7
282 (Aug 26)	0.0	2.0	1.3	4.7	2.7	0.7	2.0
453 (Sep 2)	0.0	1.3	4.7	6.0	4.0	2.0	4.7
604 (Sep 12)	0.0	2.7	2.0	4.0	4.0	2.0	6.0
LSD (p=.05)	0.0	3.1	3.3	4.4	3.6	1.9	4.4

Each mean an average of data from six replications.

Table 5. Mean percent boll weevil damaged square each variety and HU accumulation treatment on six observation dates in 1993 cotton insect control termination small-plot experiment. Stoneville, MS.

HU Accumulation after NAWF=5 (date)	7/22	7/26	8/2	8/16	8/23	8/30
DES 119						
0 (Aug 7)	0.7	0.7	0.0	1.3	2.0	2.7
217 (Aug 16)	0.7	0.7	2.0	1.3	2.0	4.7
296 (Aug 19)	1.3	1.3	0.7	0.7	2.0	3.3
426 (Aug 24)	0.0	0.7	0.7	2.0	0.0	5.3
LSD (p=.05)	1.6	2.1	2.7	2.9	4.6	3.2
Hartz 1244						
0 (Aug 7)	0.0	0.0	1.3	1.3	0.0	5.3
217 (Aug 16)	0.0	0.0	0.7	0.7	1.3	4.7
296 (Aug 19)	0.7	0.7	0.0	2.0	0.0	5.3
426 (Aug 24)	0.0	0.0	0.7	2.7	0.7	3.3
LSD (p=.05)	1.0	1.0	1.9	2.1	1.4	6.7
DPL 5415						
0 (Aug 16)	0.0	0.0	2.0	1.3	0.7	4.0
282 (Aug 26)	0.0	2.0	0.0	2.7	0.0	3.3
453 (Sep 2)	0.7	0.7	1.3	2.7	0.0	1.3
604 (Sep 12)	0.7	5.3	1.3	1.3	0.7	2.7
LSD (p=.05)	1.5	6.5	3.4	1.7	1.2	2.1

Each mean an average of data from six replications.

trol termination treatments to that of DES 119.

Mean lint yield per acre estimates for Deltapine 5415 in Figure 4 show no consistent or significant yield response to insect control termination treatments after NAWF=5. Deltapine 5415 variety was later reaching NAWF=5 (Aug 16) than DES 119 or Hartz 1244 (Aug 7). Varieties used in these experiments were purposely selected to have a maturity differential to test the hypothesis in cotton of different maturity dates. The planting date for all three varieties was late (May 19) because of 1993 spring weather and logistics of research planter scheduling. Therefore, the results of this test should not be used as a measure of variety performance since research management was purposely biased toward achieving late maturity.

One effect of delay in reaching NAWF=5 is illustrated in Figure 5. Deltapine 5415 reached NAWF=5 9 days later than DES 119 and Hartz 1244 but the date it reached NAWF=5 + 750 HU (earliest date for defoliation) was 15 days later than DES 119 and Hartz 1244. These are 15 extra days to encounter late-season weather potentially unfavorable for boll maturity and to encounter late-season insect infestations. A chart of daily heat units in Figure 6 shows a period of negative heat units about September 15 before late protected Deltapine 5415 bolls were mature. Although temperatures rebounded before defoliation, the cool nights and negative HU accumulation may have affected efficient boll maturity. Also, a late (Sep 23) beet armyworm damage rating shows higher average damage rating in Deltapine 5415 than in DES 119 and Hartz 1244 (Table 6). These observations suggest that lack of yield response to insect control after NAWF=5 in Deltapine 5415 may have been the result of unfavorable mid-September temperatures for efficient boll maturity and/or leaf damage by a late beet armyworm

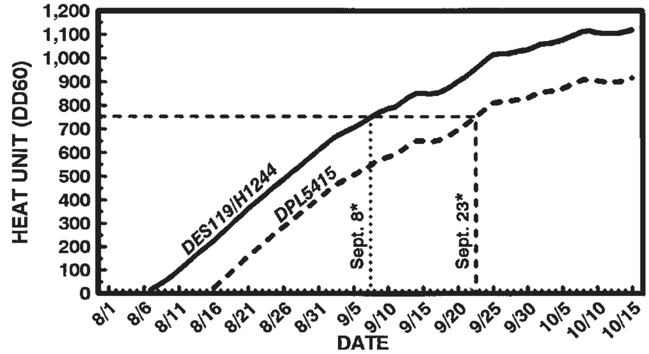

Figure 5. HU accumulation after NAWF=5 in three cotton varieties with date of NAWF=5 + 750 HU (earliest defoliation date) indicated. *Sep 8 was the earliest possible defoliation date for DES 119 and Hartz 1244, and Sep 23 was earliest possible defoliation date for Deltapine 5415. Temperature data from USDC, NOAA, Stoneville Agricultural Weather Service Center.

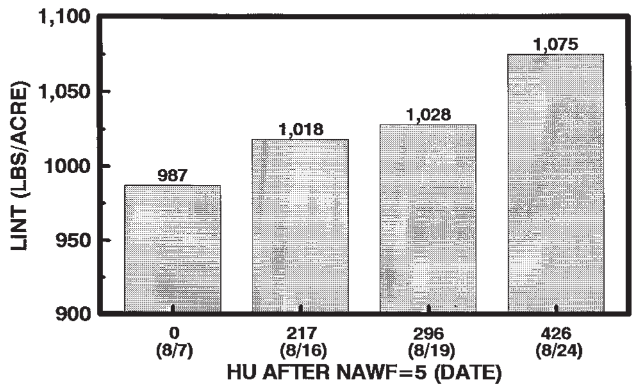

Figure 3. Average lint per acre yield for cotton insecticide termination treatments, Hartz 1244 cotton variety, 1993 experiment at Stoneville, MS. Harvested Oct. 11. LSD (p=.05) = 85 and CV = 6.7.

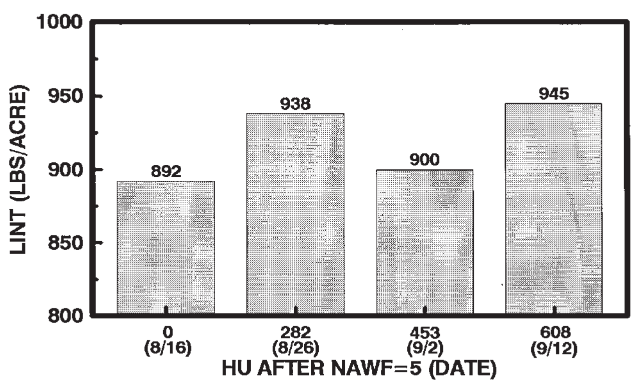

Figure 4. Average lint per acre yield for cotton insecticide termination treatments, Deltapine 5415 cotton variety, 1993 experiment at Stoneville, MS. Harvested Oct. 11. LSD (p=.05) = 102 and CV = 9.

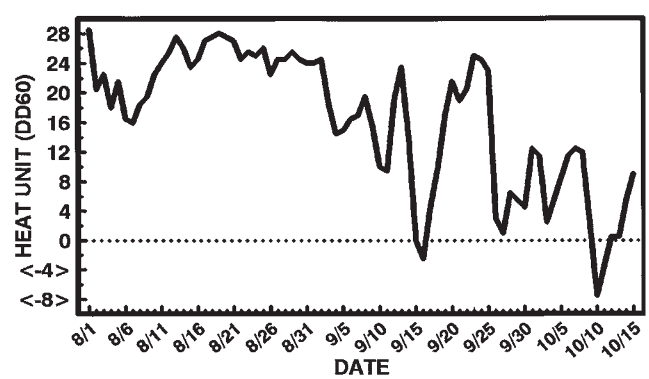

Figure 6. Daily heat units for the period Aug. 1 to Oct. 15, 1993. Temperature data from U.S. Department of Commerce, NOAA, Stoneville Agricultural Weather Service Center, Stoneville, MS.

Table 6. Mean late season beet armyworm leaf damage ratings, 0-10 where 0 = no damage and 10 = 100% of leaves damaged for each variety and HU accumulation treatment in 1993 cotton insect control termination small-plot experiment. Stoneville, MS.

HU Accumulation after NAWF = 5 (date)	Observation Date 9/23
DES 119	
0 (Aug 7)	6.2
217 (Aug 16)	5.3
296 (Aug 19)	3.2
426 (Aug 24)	5.2
LSD (p=.05)	1.7
Hartz 1244	
0 (Aug 7)	5.8
217 (Aug 16)	6.3
296 (Aug 19)	6.8
426 (Aug 24)	6.5
LSD (p=.05)	1.0
DPL 5415	
0 (Aug 16)	6.8
282 (Aug 26)	7.7
453 (Sep 2)	9.2
604 (Sep 12)	7.3
LSD (p=.05)	1.7

Each mean an average of data from six replications.

infestation at a time when foliage was needed for boll maturity.

Field Trial, Small Plot, 1994

Bollworm/tobacco budworm infestation and damage data are summarized in Table 7 for eggs, larvae and larval damaged squares on two dates, July 6 and August 15, one of which (Aug 15) followed two attempts to artificially infest the plots with neonate tobacco budworm larvae. The data show essentially no evidence of a natural infestation July 6 or establishment August 15 of an infestation by artificial means. Mean percent damaged bolls data presented for observations September 9 show that by the time of defoliation a measurable level of boll damage by bollworm/tobacco budworm larvae had occurred.

Lint yield means for the five insect control termination treatments are shown in Figure 7. Differences in average yields for the treatments were not statistically significant (LSD p=.05). Although the damage potential was low (Table 7), these data show a trend for a yield plateau in response to insecticide applications at NAWF=5 + 392 HU.

NAWF and NACB data for the 1994 small-plot experiment are summarized in Figure 8. The crop was planted at an optimum time, April 27, and was an early-maturing variety, DES 119. NAWF=5 occurred July 29 (average of all plots in the test). HU accumulation after NAWF=5 reached

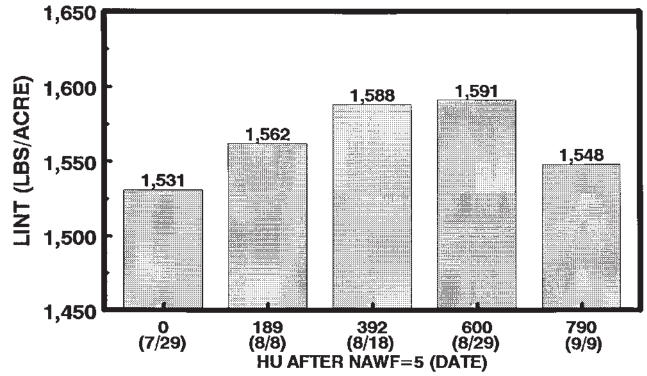

Figure 7. Average lint per acre yield for cotton insecticide termination treatments, DES 119 cotton variety, 1994 experiment at Stoneville, MS. Harvested Oct. 4. LSD (p=.05) = 65 and CV = 3.5.

Table 7. Mean bollworm/tobacco budworm infestation and damage data in 1994 insect control termination small-plot experiment. Stoneville, MS.

Treatment: HU Accumulation After NAWF=5[1]	Observation Date 7/6	8/15	9/9
Eggs/100 Terminals			
0	0	0	
189	0	0	
392	0	0	
600	0	0	
790	0	0.8	
Larvae/100 Terminals			
0	0	0	
189	0	0	
392	0	0	
600	0	0	
790	0	0	
% Damaged Squares			
0	0	0	
189	0	0	
392	0	0	
600	0	0	
790	0	0	
% Damaged Bolls			
0			6.7
189			6.7
392			8.8
600			6.8
790			4.7
		LSD (p=.05)	3.3
		CV 41.1	

Plots were infested with neonate tobacco budworm larvae from eggs obtained from USDA, ARS Southern Insect Management Laboratory, Stoneville, MS. Infestation dates: August 4 and 11, 1994.

[1]Dates of treatment termination: NAWF=5 + 0 HU (Jul 29), NAWF=5 + 189 HU (Aug 8), NAWF=5 + 392 HU (1Aug 8), NAWF=5 + 600 HU (Aug 29), NAWF=5 + 790 HU (Sep 9).

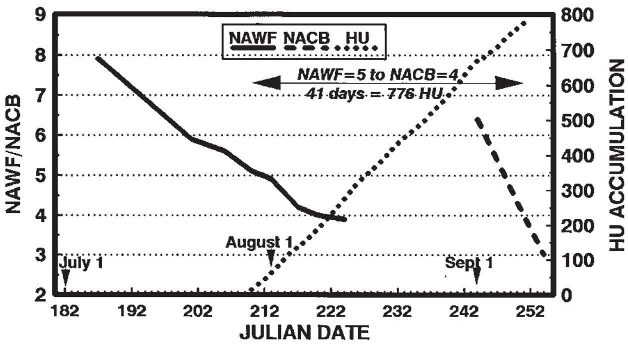

Figure 8. Chart of NAWF (node above white flower), NACB (node above cracked boll), and HU accumulation (Heat Unit = DD60) averages for all plots in 1994 small-plot replicated experiment, DES 119 cotton variety. Stoneville, MS.

and slightly exceeded 750 HU on September 6, i.e. 39 days. Bourland et al. (1993) showed 750 HU after NAWF=5 was probably the minimum time needed to mature the NAWF=5 blooms and 850 HU was probably optimum HU needed. A second measure of when to defoliate cotton was NACB=4. When the topmost first position harvestable boll is four nodes above a first position cracked boll (NACB=4) the crop is sufficiently mature for defoliation without an adverse effect on yield or lint quality (Kerby et al. 1992, Supak et al. 1993). NACB=4 (average of all plots) was projected to have been reached September 8 based on two NACB counts, September 1 when NACB=6.4, and September 7 when NACB=4.3. These measures of the interval between NAWF=5 and crop maturity indicate that blooms set later than NAWF=5 would have been terminated before maturity by defoliation even if protected from insect damage.

Field Trial, Small Plot, 1995

Insect infestation and damage data for five observation dates after NAWF=5 are summarized in Table 8. There are few significant differences in treatment means except for boll weevil damaged squares on August 27. However, the mean infestation levels shown for the treatments indicate a potential for damage to susceptible cotton bolls.

Lint yield data are summarized in Figure 9. Average lint per acre for treatment NAWF=5 + 386 HU is significantly higher (LSD p = .05) than for treatment NAWF=5 + 137 HU. Yield responses show peak yield at NAWF=5 + 386 HU. These data support the hypothesis that cotton insect control can be terminated at about NAWF=5 + 350 HU with no adverse effect on yield.

Field Trial, Small Plot, 1996

Insect infestation and damage data for five observation dates after NAWF=5 are summarized in Table 9. These observations after NAWF=5 were started about 10 days later than the optimum time to start and some treatment effects on insect infestation and damage may have been missed. Mean percent damaged squares August 9 show higher counts in earlier terminated treatments. Tarnished plant bug nymphs and adults were higher in the earlier terminated treatments August 9 and 13. These differences were not statistically significant, but infestation levels were

Table 8. Mean infestation and damage data on five observation dates after NAWF=5, 1995 insect control termination experiment, small plots. Leflore County, MS.

Treatment: HU	Observation Date				
Accumulation after NAWF=5[1]	8/11	8/17	8/22	8/27	9/5
Bollworm/Tobacco Budworm Eggs per 100 Terminals					
137	2.7	2.7	4	4	0
277	0	0	8	2.7	0
386	0	4	12	2.7	0
488	0	6.7	6.7	10.7	0
631	0	4	8	9.3	0
LSD (0.05)	1.9	9.1	18.2	10.3	0
Bollworm/Tobacco Budworm Larvae/100 Terminals					
137	0	0	0	8	2.7
277	0	0	0	1.3	2.7
386	0	0	1.3	1.3	4
488	0	0	0	2.7	1.3
631	0	0	1.3	1.3	0
LSD (0.05)	0	0	2.4	8.0	5
Bollworm/Tobacco Budworm % Damaged Square					
137	2.7	0	4	8	2.7
277	0	1.3	5.3	5.3	4
386	0	2.7	2.7	5.3	5.3
488	0	0	2.7	9.3	2.7
631	0	2.7	4	6.7	1.3
LSD (0.05)	1.9	5	9.8	9.6	6
Boll Weevil % Damaged Squares					
137	0	0	1.3	14.7	4
277	0	1.3	0	12	8
386	1.3	0	1.3	4	5.3
488	0	0	0	9.3	4
631	0	1.3	0	4	0
LSD (0.05)	1.9	2.9	2.9	9.9	9.9
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals					
137	0	0	0	12.0	21.3
277	0	0	0	2.7	5.3
386	0	0	0	0.0	2.7
488	0	1.3	0	12.0	10.7
631	0	2.7	0	0.0	1.3
LSD (0.05)	0	4.6	0	20.2	28.1

[1]NAWF=5 occurred on Aug 3. Dates of treatment termination were: NAWF=5 + 137 HU (Aug 8), NAWF=5 + 277 HU (Aug 14), NAWF=5 + 386 HU (Aug 18), NAWF=5 + 488 HU (Aug 22), and NAWF=5 + 631 HU (Aug 28).

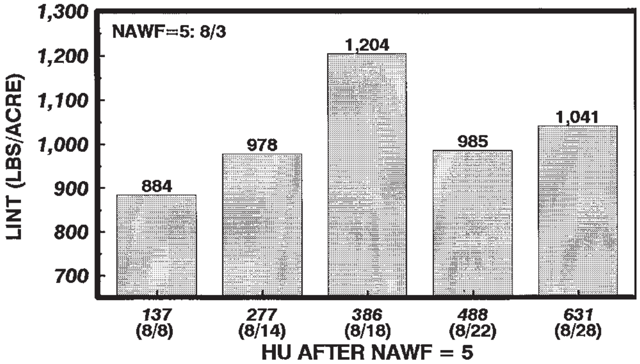

Figure 9. Average lint per acre yield, cotton insecticide termination treatments, Stoneville 474 cotton variety, 1995 experiment in Leflore County, MS. Harvested Oct. 2. Skip-row (2 x 1) data converted to solid planting (land acre) basis. LSD (p =.05) = 212 and CV = 11.

Table 9. Mean infestation and damage data on five observation dates after NAWF=5, 1996 insect control termination experiment, small plots. Carroll County, MS.

Treatment	Observation Date				
HU Accumulations after NAWF=5[1]	8/6	8/9	8/13	8/23	8/30
Bollworm/Tobacco Budworm Eggs per 100 Terminals					
98	2.6	4.6	0.0	0.0	0.6
287	4.0	5.4	1.4	0.6	1.4
381	2.0	4.0	1.4	0.6	2.0
712	—	4.0	2.6	2.0	2.6
LSD (p=.05)	7.6	3.4	2.2	3.6	3.0
Bollworm/Tobacco Budworm Larvae per 100 Terminals					
98	3.4	0.6	0.6	0.0	0.0
287	0.0	0.6	0.0	0.0	0.0
381	0.6	0.0	0.6	0.0	0.0
712	—	0.0	0.6	0.0	0.0
LSD (p=.05)	3.8	1.2	2.2	0.0	0.0
Bollworm/Tobacco Budworm % Damaged Squares					
98	4.0	6.6	5.4	1.4	0.0
287	1.4	6.6	4.6	0.0	0.0
381	2.0	2.0	4.0	0.0	0.0
712	—	3.4	6.6	13.4	3.4
LSD (p=.05)	8.4	4.1	4.6	4.0	6.6
Boll Weevil % Damaged Squares					
98	2.0	1.4	2.6	2.0	0.0
287	0.6	2.0	3.4	2.6	0.0
381	0.6	0.6	6.6	2.0	0.0
712	—	1.4	2.0	1.4	0.6
LSD (p=.05)	1.6	3.8	7.8	2.4	2.0
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals					
98	5.3	14.7	22.7	12.7	1.3
287	9.3	12.7	29.3	11.3	0.7
381	6.0	7.3	31.3	8.0	4.0
712	—	6.0	14.7	23.3	8.0
LSD (p=.05)	7.8	9.5	13.4	7.7	5.3

[1]NAWF=5 occurred Jul 17. Dates of treatment termination were: NAWF=5 + 98 HU (Jul 20), NAWF=5 + 287 HU (Jul 29), NAWF=5 + 381 HU (Aug 3), and NAWF=5 + 712 HU (Aug 20).

high enough for potential damage to susceptible cotton bolls. Unexplained significant treatment effects were higher percent damaged squares and tarnished plant bug counts on August 23 and 30 in the NAWF=5 + 712 HU treatment (sprayed four times after NAWF=5 and last sprayed August 20).

Yield data from the replicated small-plot experiment are summarized in Figure 10. The crop was relatively early and reached NAWF=5 July 17. Yield differences were not statistically significant but highest average yield was in the treatment treated until NAWF=5 + 381 HU.

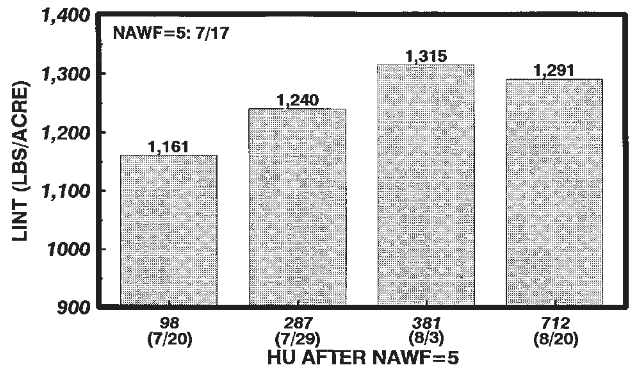

Figure 10. Average lint per acre yield, cotton insecticide termination treatments, Sure Grow 125 cotton variety, 1996 experiment in Carroll County, MS. Harvested Sep. 23. Skip-row (2 x 1) data converted to solid planting (land acre) basis. LSD (p= .05) = 170 and CV = 7.

Field Trials, Large Plot, 1994

Lint weight in grams per boll and percent boll set for bolls produced by flowers at NAWF=5 and the two nodes above NAWF=5 are shown in Table 10. These data (no statistical analysis) show the declining value of bolls from blooms after NAWF=5 both in terms of lint weight produced and probability of boll set and show similar trends to data presented by Bourland et al. (1992). Parvin (1992) also concluded that of the top three bolls in a crop the boll three nodes below the topmost boll, which he defined as the "cutout" position, was the last boll with sufficient value to justify protecting with an insecticide application. NAWF=5 in our data appears to be equivalent to the boll described by Parvin as the topmost boll worth protecting to harvest.

Comparisons of insect control termination treatment means of several parameters measured in the large-plot experiments in 1994 are shown in Table 11. Split-plot analysis of variance showed no significant effect of early-season insecticide treatments and no significant interaction between early-season insecticide treatment and insect control termination treatment. Therefore, only comparisons of insect control termination treatments are presented. The

Table 10. Lint weight in grams per boll and percent boll set for top three bolls in large-plot insect control termination experiment in 1994.

Location		Boll Number* NAWF=5	NAWF=5+1	NAWF=5+2
Average Lint Weight per Boll (g)				
Sunflower Co., MS	FS**	1.1	0.7	0.4
	ET	0.7	0.5	0.3
Holmes Co., MS	FS	1.5	1.2	1.2
	ET	1.3	1.8	—
Bolivar Co., MS	FS	—	—	0.6
	ET	1.6	1.2	0.5
Average		1.2	1.1	0.6
Percent Boll Set				
Sunflower Co., MS	FS**	74	35	18
	ET	70	29	9
Holmes Co., MS	FS	58	25	13
	ET	58	13	3
Bolivar Co., MS	FS	55	30	25
	ET	68	50	18
Average		64	30	14

*Represents boll produced from a bloom at NAWF=5 and at the 2 nodes above it.
**FS = Full season insecticide use.
ET = Early termination insecticide use.

average interval expressed in HU between NAWF=5 and the last insecticide treatment was 222 HU for the early termination treatment compared to a 527 HU interval for the full-season treatment. The average total HU accumulation between NAWF=5 and NACB=4 was 743 HU for the full-season treatment and 735 for the early termination treatment. These were similar to the HU interval between NAWF=5 and NACB=4 shown in the 1994 small-plot experiment, and further confirms the probability that bolls

Table 11. Comparison of means of various parameters for a full-season insect control program and an early termination of insect control treatment based on monitoring node above white flower (NAWF), large field plots, 1994.

Parameter	Early Termination	Full Season
HU accumulation: NAWF=5 to insect control termination	222 b*	527 a
HU accumulation: Insect control termination to NACB=4	513 a	216 b
Total HU accumulation: NAWF=5 to NACB=4	735	743
Insect control costs ($/acre)	107 b	122 a

* Means represent data from four sites and two subplots per site. Sites were located in Bolivar, Leflore, Sunflower, and Yazoo Counties, Mississippi. Paired means in rows followed by the same letter do not significantly differ (Duncan's MRT, p=.05).

set later than NAWF=5 will be terminated as immature bolls by defoliation.

Insect control cost was significantly lower ($15/acre lower) for the early termination treatment than for the full-season treatment.

Lint yield data from four sites and two subplots per site are presented in Table 12. Average lint per acre yields for the early termination treatment and full-season treatment were similar and the 12-pound difference was not statistically significant (LSD p=.05). However, differences between per acre estimates of subplot yield ranged from +135 pounds (higher yield in early termination treatment) to <-164> pounds (higher yield in full-season treatment). Since it is important to know if these treatments are the same, an analysis was conducted to determine the power of the test. Power is the probability of detecting a biologically important difference if such does exist. With a power of

Table 12. Average lint yield per acre for early termination and full-season treatments, yield differences and additional insecticide application made to full-season plots. Data presented per farm site and two subsamples per site at four sites in the Mississippi Delta, 1994.

Site (Farm) Number	Split-plot Number	Lint per Acre Early Termination	Full Season	Difference[2]	Additional Insecticide (After NAWF=5 + 350 HU)
1	1	1,498	1,363	135	4
1	2	1,247	1,411	<-164>	4
2	1	1,102	1,022	80	1
2	2	958	908	50	1
3	1	933	959	<-26>	1
3	2	877	954	<-77>	1
4	1	1,393	1,322	71	1
4	2	1,480	1,452	28	1
Mean[1]		1,186	1,174	12	1.8
Minimum detectable mean difference (90% power)[3]				116	

[1]Means not significantly different (LSD p=.05 = 131 lbs lint), CV = 4.9.
[2]Yield difference = (ET-FS), where a negative difference represents higher yield in full-season treatment.
[3]The minimum mean difference necessary to show biologically important difference, where the minimum detectable mean difference $= s_{\bar{x}} * \{(t_{\alpha .05/2,\, n-2}) + (t_{\beta .1,\, n-2})\}$

90%, this difference was 116 pounds of lint (Table 12). It is typical for cotton insecticide field experiments to require treatment mean differences of 50 to 100 pounds of lint/acre or more for statistical significance (i.e. using tests such as least significant difference and Duncan's Multiple Range Test).

There were an average of 1.8 more insecticide applications after NAWF=5 + 350 HU in the full-season treatment than in the early-termination treatment (Table 12). Cochran et al. (1994) reported an average savings of 2.65 insecticide applications in southeast Arkansas where the NAWF=5 + 350 HU termination rule was used.

Field Trials, Large plot, 1995

Bollworm/tobacco budworm larval-damaged squares data for 7 of the 13 sites studied in 1995 are summarized in Table 13. These data show a fairly high infestation with presumed damage potential for susceptible cotton.

Lint yield data from the seven test sites with insect pest damage potential are presented in Table 14. Means, or sample weight per treatment for sites with no subplots, are presented for each cooperating farm site. Average lint per acre yield for the early termination and full-season treatments were not different (LSD p=.05). Yield difference averaged 4 pounds per acre for the seven sites and ranged from <-59> pounds lint/acre higher in the full-season treatment to 64 pounds lint/acre in the early termination treatment. For a power of 90% probability of detecting a difference between the two treatments, the minimum mean lint yield difference is 89 pounds/acre. The additional number of insecticide applications made to full-season treatments after NAWF=5 + 350 HU is also shown for each farm. The mean for the seven farm sites presented in Table 14 is an additional 2.3 insecticide applications after NAWF=5 + 350 HU.

Table 13. Mean peak percent bollworm/tobacco budworm larval damaged squares in early termination and full season treatments after NAWF=5 + 350 HU. Data only from seven farms where infestation potential was sufficient to test the early termination hypothesis. Large field-plot trials, 1995.

	Peak Percent Bollworm/Tobacco Budworm Damaged Squares			
Site (Farm) Number	NAWF=5 + 350 HU Date	Early Termination	Full Season	Date of Peak Damage
1	8/5	9.0	6.0	8/28
2	7/22	44.0	24.0	7/31
3	8/12	66.0	11.0	8/30
4	8/18	—	—	—
5	8/11	7.0	4.0	8/24
6	8/14	5.0	6.0	8/30
7	8/9	53.0	20.0	8/21

Infestation data are missing for site 4, but site is included because consultant found high infestations after NAWF=5 + 350 HU in another area of the field.

Table 14. Average lint yield per acre for early-termination and full-season treatments and additional insecticide applications made to full-season plots. Data presented per farm site and mean for seven large-plot test sites in the Mississippi Delta, 1995.

Site (Farm) Number	Replications (Subsamples) per Treatments	Lint per Acre: Early Termination	Lint per Acre: Full Season	Difference[2]	Additional Insecticide (After NAWF=5 + 350 HU)
1	1	1,153	1,117	36	4
2	1	869	842	27	5
3	2	885	944	<-59>	1
4	1	1,501	1,437	64	2
5	2	1,074	1,083	<-10>	1
6	3	739	796	<-56>	1
7	3	1,083	1,056	27	2
Mean[1]		1,044	1,039	4	2.3
Weighted mean difference[3]				<-8>	
Minimum detectable mean difference (90% power)[4]				89	

[1]Means not significantly different (LSD p=.05 = 44 lbs lint), CV = 3.2.

[2]Yield difference = (ET-FS), where a negative difference represents higher yield in full-season treatment.

[3]Weighted by replication differences within sites.

[4]The minimum mean difference necessary to show biologically important difference, where the minimum detectable mean difference = $s\bar{x} * \{(t\alpha.05/2, n-2) + (t\beta.1, n-2)\}$.

Field Trials, Large Plot, 1996

Insect infestation and damage data after NAWF=5 + 350 HU are summarized in Tables 15-20. These data show infestation levels ranging from relatively heavy at site 1 in Washington County to light to moderate at other sites. Site 6 was infested with tarnished plant bugs after NAWF=5 + 350 HU and the additional full-season treatments targeted tarnished plant bug. The six sites were judged to have infestation potential sufficient to damage susceptible bolls after NAWF=5 + 350 HU.

Lint yield data for the six large-plot test sites are summarized in Table 21. Mean yields for the two treatments were not significantly different. Yield differences for five sites were within the range of expected variation. The yield difference for site 6 was 175 pounds lint/acre and may represent a real difference caused by late-season tarnished plant bugs or by greater susceptibility to damage of late-season bolls in skip-row cotton. Site 6 was planted in a 2 x 1 skip-row pattern and was the only 1996 site with a skip-row planting pattern. When data of the two-treatment, three-replicate test site are analyzed, the 175 lb lint/acre yield difference was not statistically significant. Therefore, it may represent normal variation for the test site.

Analysis of yield differences for all replications within sites indicated that for a power of 90% probability of detecting a difference between the two treatments, the minimum mean lint yield difference is 94 pounds/acre. An average of 2.2 additional insecticide applications were made to the full-season treatment (Table 21).

The weather-based rule for insect control termination was tested on one of the late crops monitored in 1996. The early-termination treatment (weather-based) reached NAWF=5 August 16, and the date of latest bloom with a 50% probability of maturing a harvestable boll by October 1 (projected defoliaiton date) was also August 16. In this case, the weather-based last effective bloom date was the same as NAWF=5. Insect control was terminated in the

Table 15. Mean infestation and damage data after NAWF=5 + 350 HU. Site 1 large-plot field trial Mississippi Delta, Washington County, 1996.

	Observation Date			
Treatment	**8/9**	**8/13**	**8/21**	**8/28**
Bollworm/Tobacco Budworm Eggs per 100 Terminals				
ET	2	3	18	9
FS	5	5	17	11
LSD (p=.05)	27	13	40	12
Bollworm/Tobacco Budworm Larvae per 100 Terminals				
ET	10	10	7	11
FS	2	3	3	11
LSD (p=.05)	15	14	5	10
Bollworm/Tobacco Budworm Larval % Damaged Squares				
ET	17	19	21	32
FS	3	7	9	29
LSD (p=.05)	12	24	9	6
Bollworm/Tobacco Budworm Larval % Damaged Bolls				
ET	0	3	21	13
FS	0	1	10	14
LSD (p=.05)	0	5	13	8
Boll Weevil % Damaged Squares				
ET	0	2	5	3
FS	1	0	9	3
LSD (p=.05)	3	9	23	9
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals				
ET	10	11	0	0
FS	2	7	0	0
LSD (p=.05)	17	9	0	0

ET = early termination treatment where insecticide applications stopped **at or before** NAWF=5 + 350 HU.
FS = full season treatment where insecticide applications stopped **after** NAWF=5 + 350 HU (farmer standard).

Table 16. Mean infestation and damage data after NAWF=5 + 350 HU. Site 2 large-plot field trial Mississippi Delta, Washington County, 1996.

	Observation Date			
Treatment	**8/7**	**8/14**	**8/20**	**9/3**
Bollworm/Tobacco Budworm Eggs per 100 Terminals				
ET	2	3	20	26
FS	5	7	23	17
LSD (p=.05)	26	21	40	8
Bollworm/Tobacco Budworm Larvae per 100 Terminals				
ET	1	2	17	13
FS	0	0	12	5
LSD (p=.05)	3	5	30	10
Bollworm/Tobacco Budworm Larval % Damaged Squares				
ET	1	0	14	31
FS	2	2	8	25
LSD (p=.05)	8	5	15	26
Bollworm/Tobacco Budworm Larval % Damaged Bolls				
ET	11	0	0	5
FS	10	0	0	5
LSD (p=.05)	24	0	0	6
Boll Weevil % Damaged Squares				
ET	1	2	35	35
FS	1	5	47	37
LSD (p=.05)	6	15	44	40
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals				
ET	22	9	0	0
FS	21	7	0	0
LSD (p=.05)	22	8	0	0

ET = early termination treatment where insecticide applications stopped **at or before** NAWF=5 + 350 HU.
FS = full season treatment where insecticide applications stopped **after** NAWF=5 + 350 HU (farmer standard).

early termination treatment at NAWF=5 + 350 HU on September 3. Full-season treatment received one additional insecticide application September 11. There was no significant yield difference.

Economic Implications

Cotton insect control costs have risen since 1992 to the level where there is little or no profit to be realized from cotton production in the Mississippi Delta. Tables 22, 23, and 24 present the cotton insect control costs for the various insect groups in the Mississippi Delta for 1994 and 1995 (Scott et al., 1996). These data, which reflect average insect control costs for the Mississippi Delta, indicate that in the South Delta in 1994, 37.9% of all insect control costs were spent on bollworm/tobacco budworm. In the north Delta, 50.5% of total costs were spent on this insect complex. The survey in 1995 indicated that for the whole Delta, 62.5% of all insect control costs were for bollworm/tobacco budworm control. Use of the NAWF=5 + 350 HU rule for terminating cotton insecticide applications provides an opportunity to reduce cost of controlling bollworm, tobacco budworm, and boll weevil. Cost of controlling diapausing boll weevils as an investment in next year's crop is not considered in these analyses.

Cotton fruiting fits the classic agronomic production response curve in Type I plants (Figure 11). While added insect control inputs at the end of the production period may increase yield slightly, this increase in yield probably will have a lower value than the cost of additional insect control inputs. The cost of insecticide treatment increases as the cotton plant progresses toward maturity (Figure 12). This projected cost of insecticide treatment indicates that an insecticide plus application on August 15 averaged $14.62 in 1995. The decline in amount of additional yield produced on the top three nodes of the referenced crops (Figure 11) indicates that additional yield potential on these nodes

Table 17. Mean infestation and damage data after NAWF=5 + 350 HU. Site 3 large-plot field trial Mississippi Delta, Washington County, 1996.

	Observation Date			
Treatment	**8/7**	**8/14**	**8/19**	**8/26**
Bollworm/Tobacco Budworm Eggs per 100 Terminals				
ET	0	5	15	23
FS	0	1	7	18
LSD (p=.05)	0	6	26	22
Bollworm/Tobacco Budworm Larvae per 100 Terminals				
ET	1	1	5	16
FS	2	0	1	13
LSD (p=.05)	8	3	10	10
Bollworm/Tobacco Budworm Larval % Damaged Squares				
ET	10	3	5	35
FS	13	2	5	20
LSD (p=.05)	18	6	8	14
Bollworm/Tobacco Budworm Larval % Damaged Bolls				
ET	—	2	2	9
FS	—	2	3	9
LSD (p=.05)	—	15	8	5
Boll Weevil % Damaged Squares				
ET	8	27	29	33
FS	8	21	18	22
LSD (p=.05)	10	8	25	22
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals				
ET	—	9	3	0
FS	—	9	2	0
LSD (p=.05)	—	18	18	0

ET = early termination treatment where insecticide applications stopped **at or before** NAWF=5 + 350 HU.
FS = full season treatment where insecticide applications stopped **after** NAWF=5 + 350 HU (farmer standard).

Table 18. Mean infestation and damage data after NAWF=5 + 350 HU. Site 4 large-plot field trial Mississippi Delta, Washington County, 1996.

	Observation Date		
Treatment	**8/19**	**8/26**	**9/3**
Bollworm/Tobacco Budworm Eggs per 100 Terminals			
ET	7	9	3
FS	5	9	3
LSD (p=.05)	8	9	13
Bollworm/Tobacco Budworm Larvae per 100 Terminals			
ET	1	7	1
FS	1	5	1
LSD (p=.05)	5	17	5
Bollworm/Tobacco Budworm Larval % Damaged Squares			
ET	3	5	2
FS	3	7	1
LSD (p=.05)	10	17	8
Bollworm/Tobacco Budworm Larval % Damaged Bolls			
ET	1	0	1
FS	0	0	1
LSD (p=.05)	3	0	5
Boll Weevil % Damaged Squares			
ET	0	0	0
FS	0	0	0
LSD (p=.05)	0	0	0
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals			
ET	0	0	0
FS	0	0	0
LSD (p=.05)	0	0	0

ET = early termination treatment where insecticide applications stopped **at or before** NAWF=5 + 350 HU.
FS = full season treatment where insecticide applications stopped **after** NAWF=5 + 350 HU (farmer standard).

Table 19. Mean infestation and damage data after NAWF=5 + 350HU. Site 5 large-plot field trials, Mississippi Delta, Yazoo County, 1996.

Treatment	Observation Date				
HU Accumulations after NAWF=5[1/]	8/8	8/15	8/20	8/29	9/4
Bollworm/Tobacco Budworm Eggs per 100 Terminals					
ET	8	0	0	0	0
FS	16	4	8	2	0
LSD (p=.05)[1]					
Bollworm/Tobacco Budworm Larvae per 100 Terminals					
ET	4	4	2	0	0
FS	4	0	4	0	0
LSD (p=.05)					
Bollworm/Tobacco Budworm % Larval Damaged Squares					
ET	0	8	2	0	0
FS	0	0	6	6	0
LSD (p=.05)					
Bollworm/Tobacco Budworm % Larval Damaged Bolls					
ET	0	4	0	0	0
FS	0	0	0	2	0
LSD (p=.05)					
Boll Weevil % Damaged Squares					
ET	2	2	2	0	0
FS	16	14	4	16	18
LSD (p=.05)					
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals					
ET	20	0	0	0	0
FS	22	0	0	0	0
LSD (p=.05)					

ET = early termination treatment where insecticide applications stopped **at or before** NAWF=5 + 350 HU.
FS = full season treatment where insecticide applications stopped **after** NAWF=5 + 350 HU (farmer standard).
[1]Site 5 was not replicated, no statistical analysis.

Table 20. Mean infestation and damage data after NAWF=5 + 350 HU. Site 6 large-plot field trial, Mississippi Delta, Carroll County, 1996.

	Observation Date			
Treatment	8/6-9	8/13	8/20	8/28
Bollworm/Tobacco Budworm Eggs per 100 Terminals				
ET	4	4	3	2
FS	5	5	6	3
LSD (p=.05)	*	6	12	8
Bollworm/Tobacco Budworm Larvae per 100 Terminals				
ET	5	3	3	1
FS	1	3	3	3
LSD (p=.05)	—	9	13	5
Bollworm/Tobacco Budworm % Larval Damaged Squares				
ET	9	13	9	8
FS	3	13	8	5
LSD (p=.05)	—	—	6	3
Bollworm/Tobacco Budworm % Larval Damaged Bolls				
ET	0	2	5	1
FS	0	1	6	2
LSD (p=.05)	—	8	20	3
Boll Weevil % Damaged Squares				
ET	0	1	2	1
FS	0	0	3	1
LSD (p=.05)	—	3	8	5
Tarnished Plant Bugs (Nymphs & Adults) per 100 Terminals				
ET	15	7	25	40
FS	2	4	16	40
LSD (p=.05)	—	8	9	—

ET = early termination treatment where insecticide applications stopped **at or before** NAWF=5 + 350 HU.
FS = full season treatment where insecticide applications stopped **after** NAWF=5 + 350 HU (farmer standard).
*ET observation on 8/6, FS observation on 8/9.

Table 21. Average lint yield per acre for early-termination and full-season treatments, yield differences, and additional insecticide applications made to full-season plots. Data presented per farm site and mean for six large-plot test sites in the Mississippi Delta – 1996.

Site (Farm) Number	Replications (Subsamples) Per Treatments	Lint Per Acre: Early Termination	Lint Per Acre: Full Season	Difference[2]	Additional Insecticide (After NAWF=5 + 350 HU)
1	3	869	887	<-18>	5
2	3	641	626	15	2
3	3	886	953	<-67>	2
4	3	1,252	1,238	14	1
5	1	1,127	1,103	24	1
6	3	1,135	1,310	<-175>	2
Mean[1]		985	1,020	<-35>	2.2
Weighted mean difference[3]				<-44>	
Minimum detectable mean difference (Power = 90%)[4]				94	

[1]Means not significantly different (LSD p=.05 = 80 lbs lint), CV = 5.4.
[2]Yield difference = (ET-FS), where a negative difference represents higher yield in full-season treatment.
[3]Weighted by replication differences within sites.
[4]The minimum mean difference necessary to show biologically important difference where the minimum detectable mean difference = $s\bar{x} * \{(t\alpha.05/2, n\text{-}2) + (t\beta.1, n\text{-}2)\}$.

would be less than the projected cost of one insecticide treatment.

Average additional insecticide applications to full-season treatments in the large-plot on-farm trials for 1994, 1995, and 1996 were 1.8, 2.3, and 2.2, respectively. The 3-year average was 2.1 additional insecticide applications applied in the full-season treatments (farmer standard) after NAWF=5 + 350 HU. This number of additional applications (2.1) at a cost of $14.62/application results in an additional production cost of $30.70/acre with no increase in yield and thus a reduction in income.

Cotton acreage in the Mississippi Delta varies each year so that precise projections of Delta-wide economic impact cannot be made. Studies have shown that 75% of cotton growers in the Mississippi Delta made insect control applications after August 12. Our studies indicate that many of these applications were unnecessary and reduced farm income. Using 2.1 applications as the average number of unnecessary applications after NAWF=5 + 350 HU, the annual cost savings would be about $20 million or more for Mississippi Delta cotton producers if the NAWF=5 + 350 HU insect control termination rule was used on 650,000 or more acres.

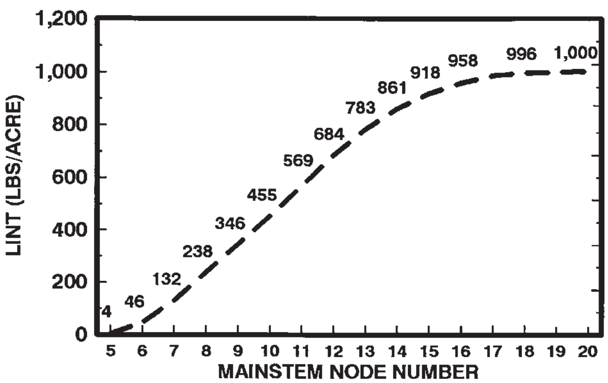

Figure 11. Cumulative lint yield per acre estimates by mainstem node. Adapted from Jenkins (1990), Parvin (1992), and G. Tupper (personal communication).

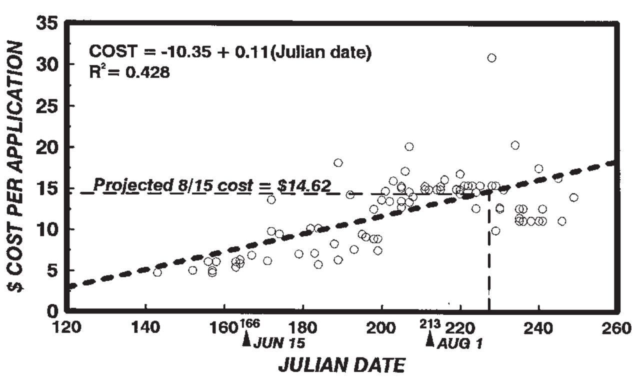

Figure 12. Insecticide costs per treatment, including application, for various dates through the 1995 growing season. Data from cost survey of 10 Mississippi Delta farms. Stoneville, MS.

Table 22. Average insect control costs for all acres of target insect (South Delta), 1994.

Target Insect	Material Cost	Application Cost	Total Cost
		$/acre	
Boll Weevil	15.22	10.72	25.94
Aphids	1.07	0.45	1.52
White Fly	0.04	0.02	0.06
Cutworm	4.82	1.47	6.29
Beet Armyworm	8.10	1.69	9.79
Loopers	0.68	0.15	0.83
Tarnished Plant Bug	7.80	2.84	10.64
Bollworm/TBW	32.35	8.34	40.69
Thrips	6.14	3.60	9.74
Fall Armyworm	0.81	0.21	1.02
Other	0.67	0.29	0.96
Total	77.70	29.78	107.48

Table 23. Average insect control costs for all acres of target insect (North Delta), 1994.

Target Insect	Material Cost	Application Cost	Total Cost
		$/acre	
Boll Weevil	9.02	4.40	13.42
Aphids	3.98	1.35	5.33
White Fly	.14	.04	.18
Cutworm	1.79	.43	2.22
Beet Armyworm	4.84	.96	5.80
Loopers	.62	.14	.76
Tarnished Plant Bug	5.99	2.73	8.72
Bollworm/TBW	39.50	9.10	48.60
Thrips	6.24	4.03	10.27
Fall Armyworm	.64	.11	.75
Other	.19	.04	.23
Total	72.95	23.33	96.28

Table 24. Average insect control costs, Mississippi Delta (North and South), 1995.

Target Insect	Material Cost	Application Cost	Total Cost
		$/acre	
Aphids	6.52	2.39	8.91
Beet Armyworm, Fall armyworm	2.92	.40	3.32
Boll weevil	6.02	3.72	9.74
Bollworm	6.47	1.26	7.73
Plant bugs, fleahoppers, lygusbugs	4.29	1.80	6.09
Spider mites	.32	.06	0.38
Budworm	51.90	8.56	60.46
Thrips	10.24	1.17	11.41
Other	.62	.10	0.72
Total	89.30	19.46	108.76

Conclusions

Results of these studies support the hypothesis that insecticide applications to cotton in late season can be significantly reduced without significantly reducing yield by using the rule of stopping insect control treatments when the crop reaches NAWF=5 + 350 HU.

When insecticide applications are applied later than NAWF=5 + 350 HU, results of these studies indicate that economic benefit may not be realized because bolls from blooms after NAWF=5 are likely to be immature at the time of defoliation and contribute little or nothing to yield.

NAWF=5 + 350 HU may not always be applicable as a rule for terminating insect control in a cotton crop because of crop production and weather factors that delay maturity. However, changing to a calendar-date rule based on probability of accumulating sufficient heat units to mature bolls is unlikely to allow much more time for crop development. Zhang et al. (1993) and Zhang et al. (1994) studied the probability of accumulating sufficient heat units for boll maturity from bloom on various dates. They showed that for an 85% probability of accumulating sufficient heat units to defoliate a mature boll by a late September or even early October defoliation date, a bloom must occur in early August. Similar calculations based on 29 years of weather data indicate this bloom date would be August 11 for an October 1 defoliation date with an 85% probability of sufficient HU in the central Mississippi Delta area (Figure 13). The latest weather based effective bloom date with a 50% probability of sufficient HU by October 1 is August 16.

Use of NAWF=5 + 350 HU rule for terminating cotton insect control provides an opportunity to reduce total pounds of insecticide applied to cotton during a growing season. Following the rule eliminates some high-rate late-season applications, which reduces environmental pollution and reduces late-season selection of insect pests for insecticide resistance.

Producers who manage for earliness in all aspects of cotton production probably will achieve the greatest benefit from using the NAWF=5 + 350 HU rule for terminating cotton insect control.

The University of Arkansas developed computer program, COTMAN, is an effective tool for handling NAWF data and aiding with the "when to quit cotton insecticide treatments" decision.

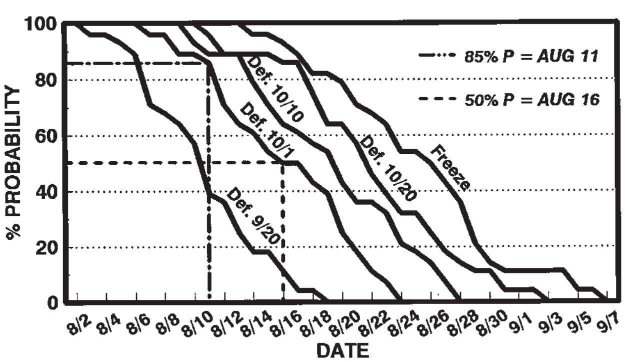

Figure 13. Probability of blooms accumulating 750 HU by defoliation. Percent probability based on 29 years of Stoneville, MS weather data. Examples of Oct. 1 defoliation date and latest bloom with 85% probability of reaching maturity and latest bloom with 50% probability of reaching maturity.

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